FIG. 10.—Free young captured on surface of the water in glass jar containing specimens of the adult. Size 1^{mm}.

" 11.—View of the head of a young Spirorbis older than the last with the beginning of the operculum and the right hand tentacle, seen from the dorsal side.

PLATE XII.

FIG. 12.—Side view of a larva of the same age.

" 13.—The same larva older, seen from the dorsal side.

" 14.—An older larva seen from the ventral side.

" 15.—Larval Spirorbis which has just begun to secrete its shell, shown with the collar and head partly protruded.

" 16.—An older larva with shell more completely formed than in the last. The head and collar are extruded. Size 2^{mm}.

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PENNSYLVANIA BEFORE AND AFTER THE ELEVATION OF THE APPALACHIAN MOUNTAINS, A STUDY IN DYNAMICAL GEOLOGY.

BY PROFESSOR E. W. CLAYPOLE.

THE geologist traveling or working among the contorted strata of Pennsylvania can scarcely escape being struck by the immense compression which the rocks of that part of the country experienced during the folding process which was the first stage in the formation of its mountain ranges. By this term I do not mean merely the condensation of the rock-masses by the tangential pressure to which the folds are due, but the actual shortening of the surface which must have resulted from the folding.

Doubtless the thought has occurred to others, but I do not recollect seeing it put forward or developed to its legitimate conclusions. Yet it is obvious that so extensive a corrugation of the earth's crust manifesting itself by the production of several wide anticlinal arches, from which the present mountains have been carved, must have been accompanied by a diminution of the area over which those strata previously extended.

To measure as nearly as practicable the extent of this contraction of the surface and to set forth the more important conclusions deducible therefrom are the objects of this paper.[1]

To prevent undue extension in treating the subject, it will be necessary to assume certain propositions. These will be here

[1] An abstract of this paper was read before the British Association at Montreal in August, 1884.

mentioned. They are, I think, now fully accepted by all dynamical geologists.

1. That cooling and consequent shrinkage taking place in the earth's heated interior, must produce and have produced tangential pressure in the hardened and cooled crust.

2. That this tangential pressure overcoming the rigidity of the crust has produced deformation or crumpling.

3. That this crumpling of the strata was the first and leading factor in the production of mountain-ranges which have been carved by meteoric action out of the folds this produced.

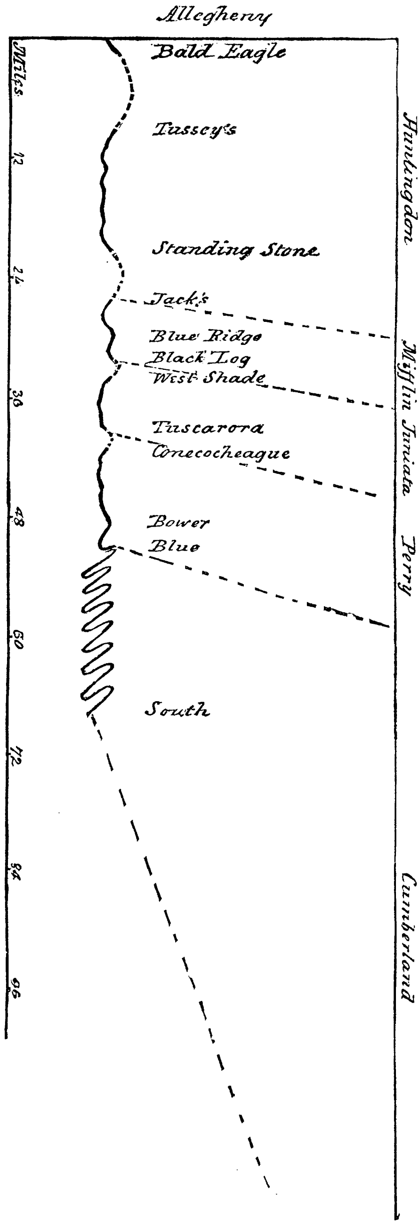
4. That the folds out of which the Appalachian mountains have been carved were formed during the later part of the Palæozoic era.

Yet further to limit the subject and bring it within the bounds of practicable treatment, another exclusion must be made. Middle Pennsylvania, from Harrisburg to Pittsburgh, is occupied by an almost continuous succession of arches of the folded Palæozoic rocks. Some of these are closely pressed, others are more open, some are long, ranging for many miles from north-east to south-west, others run only a few miles. Some involve a great breadth of country, others extend over only a few hundred yards. To take account of all these is impossible. The geography and geology of the State are not yet sufficiently known to supply the details, and the space at command is too small to discuss them if supplied. I therefore propose to omit all the less important ones and to consider only the leading mountain ranges of Appalachian Pennsylvania.

The number of these varies in different places, but not so as to seriously affect the results sought. Thirteen principal ridges traverse the middle of the State from north-east to south-west. All these may be cut by a line drawn from a point near Warrior's Mark in Huntingdon county, to another ten miles south-west of Carlisle.

These thirteen ranges are the following:

13. Allegheny mountain.
12. Bald Eagle "
11. Tussey "
10. Standing Stone "
9. Jacks "
8. Blue Ridge.
7. Black Log "
6. West Shade mountain.
5. Tuscarora "
4. Conecocheague "
3. Bower "
2. Blue "
1. South "



Section across Middle Pennsylvania, showing amount of compression of surface.

From this list I shall exclude the first because it consists in great part of gneissic rocks whose bedding is doubtful and difficult of detection, and the thirteenth because its strata are of later date than those of the other ranges. There remain, therefore, for discussion eleven distinct mountains, rudely parallel, and, for Pennsylvania, of the first order. To prevent misconception or objection I should state that all these ranges are composed, medially, of the same rock—the massive Medina sandstone—the base of the Silurian system proper in Pennsylvania. The possible error of counting the same dip more than once is, by this fact, evaded.

The line of section above mentioned is sixty-five miles long, and may be divided naturally into two parts. One extends from its north-western end to the Blue mountains, and the other from the Blue mountains to its south-eastern end. The first division is forty-nine miles long and crosses all the eleven ranges of mountains above named. The second is sixteen miles long, and crosses only the Cumberland valley.

The line lies in six counties, among which it is distributed as follows:

Blair	2	miles.
Huntingdon	24	"
Mifflin	6	"
Juniata	8	"
Perry	9	"
Cumberland	16	"
	65	

The accompanying plan exhibits the relation of the eleven ranges to one another, and the section shews the position of the bed of Medina sandstone which forms the axis of each.

The problem is now reduced to finding the length of the line representing this bed of sandstone in its present contorted condition, for that must represent, approximately at least, its original extent when spread out flat.

Taking first its north-western portion forty-nine miles in length I have drawn it as nearly as possible to scale on the accompanying diagram. I propose now to make a deduction of twenty miles for the flattish tops of the arches and bottoms of the troughs—an allowance which is, I think, in excess of the truth. This deduction leaves twenty-nine miles of strata, dipping more or less steeply, often standing nearly vertical, sometimes over-

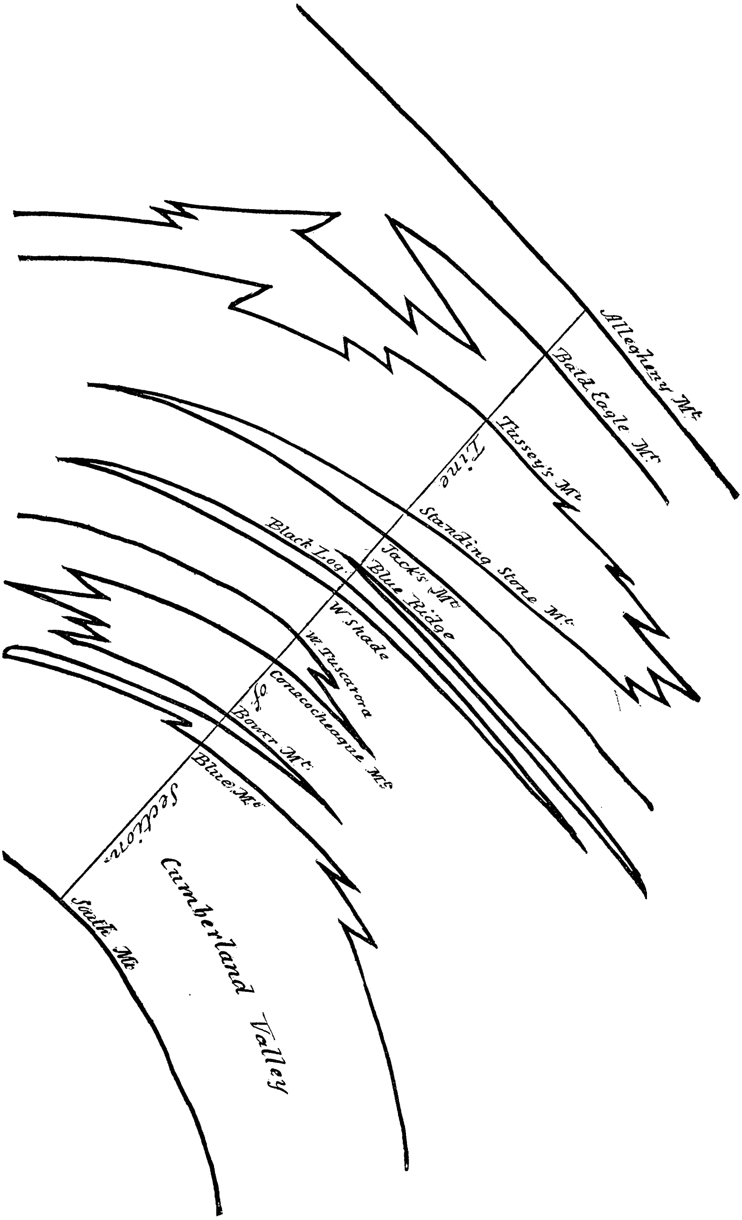
thrown and probably at most exposures approaching or exceeding a dip of 45°. Over this distance I propose to assume an average dip of 40°, which to me seems fairly to represent the facts and to be rather below than above the truth. A simple calculation then proves that these twenty-nine miles of strata, if flattened out, would measure about thirty-eight miles.

If from the accompanying section the distances representing these twenty-nine miles are taken out and measured by the scale, a result in close agreement with the above will be obtained. The two confirm each other.

In regard to the Cumberland valley the problem is more difficult. South of the Blue mountain the structure of the country is very different. Here the Medina sandstone is lost, having been entirely removed by erosion, and we are consequently compelled to adopt another stratum. The valley consists entirely of Cambro-Silurian limestone and slate dipping steeply, and the latter showing strongly developed cleavage. On the north-western sides of the arches the strata are usually inverted. It is evident at once that compression has here been much greater and the tangential compressing force much more intense than along the other portion of the line. Professor Rogers says in the Geological Survey of Pennsylvania (Vol. 1, p. 240):

"The dip of the south-eastern leg of the arch is from 45° to 60°, while that of the north-western inverted side is from 60° to 80°." "The formations repeat themselves in several narrow, short and parallel anticlinal and synclinal outcrops. They are folded into a very uniform steep south-eastern dip in a series of compressed flexures, readily discernible on the Cumberland Valley Railroad. Along the south-eastern margin of the valley so general is the inversion of the folded limestone that this formation appears everywhere to dip under the primal rocks of the South mountains, and had we not fully established their true position we might imagine the former to be the lower or older group" (p. 1113).

Adopting Professor Rogers's figures, it is clear that the results obtainable from the Cumberland valley must far exceed in proportion those above given from the counties lying farther to the north-west. The dips above stated show that the inverted sides of the arches altogether underlie the others, and the measurements obtained for them must therefore be added to those found for the south-eastern or uninverted sides. The latter will be first considered.



Mountain Ranges of Middle Pennsylvania.

In consequence of the condition of the strata it is exceedingly difficult to determine in the field the number of folds occurring in the valley. It is not probable, moreover, that they are regular or constant. The beds involved are, however, about a mile in thickness, so that there can scarcely be less than eight arches in the sixteen miles. If then for the south-eastern legs we adopt Professor Rogers's lowest angle of dip, or 45°, and for the north-western sides his lowest estimate, or 60°, and plat these to scale, we have the following result:

The Cumberland valley, sixteen miles wide, consists of at least eight overthrown anticlinal arches, the crest of each of which overlaps to some extent the base of that following it. This will be clear from an inspection of the diagram, where a single bed of rock is shown folded as required by the conditions above given. *A B C*, &c., are the successive crests of the arches formed by the stratum. *X Y* represents the present surface of the ground. *a b c* are the bases of the synclines corresponding to the arches. Taking into consideration the mid-layer of the stratum represented by *Q O S T U V*, &c., which will represent the actual length of the folded bed, a short mathematical calculation will prove that *O Q* is 3.3 times as long as *R Q*. *R Q* representing one mile, *O N* will therefore represent 6.6 miles. All the eight south-eastern legs of the arches will consequently measure about fifty-two miles.

In like manner we find that the length of the line *O R*, compared with *R Q*, is 2.7. Consequently the length of the line *O S* represents 5.4 miles and the eight north-western sides of the arches amount to forty-three miles.

Again, a reference to the figure will show that the north-western side of each arch underlies its south-eastern side, so that its whole length must be added to the figures previously obtained.

Summing up results, we find:

Twenty-nine miles at 40° dip, or	38	miles.
Eight anticlinal arches in Cumberland valley—		
South-eastern sides	52	"
North-western sides	43	"
Add twenty miles for flat strata, as previously deducted	20	"
Total	153	"

In other terms this means that a tract of the earth's surface measuring originally 153 miles from south-east to north-west has

been so crushed and compressed that its present breadth along the line of section is only sixty-five miles. Of this shortening the greater part has been suffered by the Cumberland valley, where ninety-five miles of country have been compressed into sixteen miles.

The diagram shows the distribution of the compression among the different counties. Approximately it may be represented by the following figures:

ORIGINAL AND PRESENT EXTENT OF THE COUNTIES ALONG THE LINE OF SECTION.

	Original extent.	Present extent.
Blair	2 miles.	2 miles.
Huntingdon	26 "	24 "
Mifflin	8 "	6 "
Juniata	10 "	8 "
Perry	12 "	9 "
	58	49
Cumberland	95 "	16 "
	153 "	65 "

These facts may be thus expressed. During the compression and corrugation of the crust to which the mountains of Pennsylvania owe their origin, the south-east line of Huntingdon county was moved forward two miles, that of Mifflin four miles, that of Juniata six miles, that of Perry nine miles and that of Cumberland eighty-eight miles. Consequently the whole of Mifflin county was shoved, at the least, two miles to the north-west, the whole of Juniata county four miles, the whole of Perry county six miles and the whole of Cumberland county nine miles over the underlying deeper strata. The possibility, still less the reality, of mass-motion of this kind and to this extent, has not, it seems to me, been generally recognized by geologists.

The movement of course diminished toward the north-west in consequence of the increasing resistance offered by the increasing load, and came at length to nothing beyond the limits of Pennsylvania. Ohio was the great buffer-plate against which this tremendous earth-force spent itself. The south-eastern portion of the district—the Cumberland valley—and even probably some considerable area beyond it to the south-east felt its first and mightiest pressure. There the strata were crumpled, bent, crushed and thereby thickened until it became easier to shove them bodily forward than to bend them again. They were consequently added

PLATE XV.

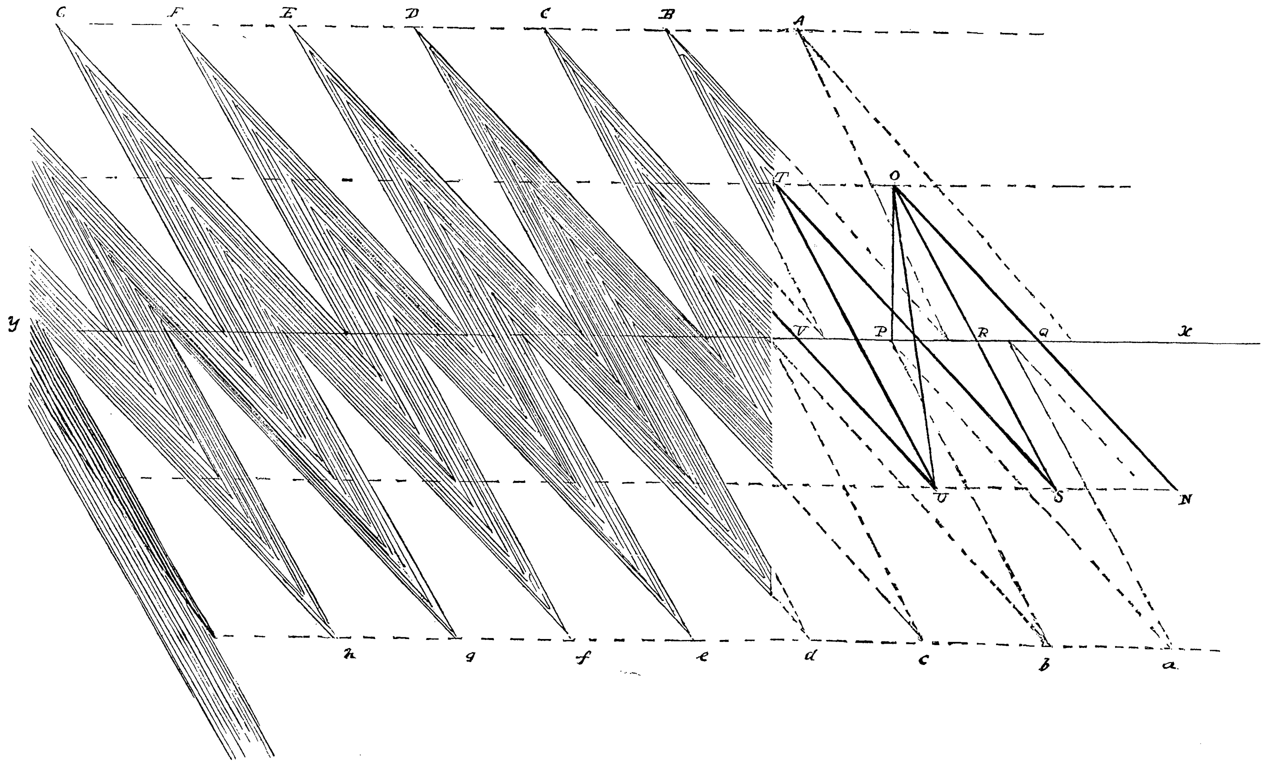


Diagram to illustrate the structure of the Cumberland valley.

as a snow-plough in front of the mighty engine, and in their turn communicated the movement and the crumpling to the north-western country beyond them.

It is possible that considerable correction might be made in these figures if more accurate details of structure were attainable. This correction might be in either direction. That it would not all tend to diminish the result seems clear from the following considerations:

(1) No account is taken of the condensation of the strata during compression.

(2) The line of section does not pass through the most distorted district.

(3) All effects of compression in and beyond the South mountain and west of the Bald Eagle range are disregarded.

(4) The summits of the arches and the bottoms of the troughs are assumed to be, but are not quite flat.

(5) No account is taken of numerous intermediate minor folds or of several faults, at some of which the older strata to the south-east have been shoved *uphill* over the edge of the newer north-western beds at an angle which observation does not yet enable us to determine.

On the other hand the height of the creases in the Cumberberland valley may be somewhat less than that shown in the diagram and assumed in the calculation. All these minor considerations cannot affect the main point at issue. The figures above given indicate a compression of the superficial layer of the crust in Pennsylvania during the process of crumpling by which eighty-eight miles of the surface have disappeared, sixty-five miles at present being all that remain from a former breadth of 153 miles. Even if only one-half of these figures be taken into account, the problem remains equally difficult. How can such a shortening of the surface be accounted for?

We are at no loss for a force competent to produce it. The tangential pressure developed by a contracting nucleus under a solid crust is amply sufficient to deform and corrugate that crust. But to realize the effect which this tangential pressure has produced is less easy.

A shortening of the circumference by eighty-eight miles is equivalent to a shortening of the diameter of the earth by about twenty-seven miles. Are we prepared to admit that the globe

actually contracted to that extent during the formation of the Appalachian earth-folds? If not, how shall the facts above stated be explained?

The suggestion has been made that the subsidence of the present bed of the Atlantic from a continental level in late Palæozoic days may have supplied the necessary compressing force and have produced the shortening here pointed out. But the cause is totally inadequate. Supposing that the whole Atlantic area had subsided from the mean height of one mile above sea-level to five miles below it at its middle or deepest point—a maximum supposition—then a short calculation will prove that the new and flattened arc so produced, of 60° in extent, would measure only about three miles less than the previously existing one. This amount, if wholly expended in crushing the thick Appalachian sediments, would evidently be far from sufficient for the solution of our problem.

Without therefore denying the occurrence of such a subsidence, we can lay it out of the case as inadequate.

Is it possible to believe that there was an accumulation of strain on the crust during preceding ages, which was relieved by the occurrence of this paroxysmal compression and corrugation. Such a supposition would meet with strong opponents in many quarters.

Mathematicians tell us that the crust cannot endure the strain which would be caused by the shrinking away of the nucleus in consequence of contraction, but must close down at once upon the latter as it sinks. Some of them add that this would be the case were it many times as resistent as now. If so, any such accumulation of strain is evidently impossible.

But there is a possibility that the interior of the earth may be of such a nature as to allow of some considerable amount of shrinkage without leaving the crust completely unsupported. This partial support might enable contraction to proceed for some time before the closure of the crust upon the shrinking nucleus followed. A cellular structure about the place of junction between the cool and heated portion might render possible such a condition of things. Our ignorance of the earth's interior is at present so dense that any supposition which does not clash with well established facts is admissible for the purpose of argument.[1]

[1] In this connection I may remark that since writing the above passage I find that

The mathematical solution of geological problems such as that now under consideration is far from being satisfactory to geologists. Without in the least undervaluing the labors of the many eminent mathematicians who have taken the subject in hand, I may plainly assert that the conditions are yet too little known to enable them to apply their processes with complete success. The mill grinds out its meal according to the nature of the grist supplied, but cannot change its quality. So the mathematical engine, of whatever kind, works out its conclusions from the premises given. If these are full and true the results cannot be false. But if these are insufficient and half unknown, or if any of them are much limited and modified, the results are to an uncertain extent invalidated. This is the case with almost all investigations dealing with the condition of the earth's interior. In order to bring them within the grasp of mathematical formulas the data of the problem are narrowed down or altered to so great a degree that the conclusion, though true for these, is false for the actual data. A logical fallacy lurks in the argument. The reasoning deals with an imaginary earth possessing certain comparatively simple characters. The conclusion when obtained is applied to the real earth, whose characters are much more complicated. The confusion lies in the employment of the term "earth" in two different senses—a logical fallacy of the first magnitude, and one whose insinuation into any geological problem must be avoided with the utmost care if conclusions of value are anticipated.

Hence without any expressed or implied disrespect to the mathematician, the geologist may receive his arguments on geo-

Dr. T. Sterry Hunt has recently, in the discussion of a different subject, put forward some views which deserve mention in this connection, and may not be without bearing upon the matter in hand. He has dwelt strongly on the universally crumpled condition of the metamorphic rocks, and has suggested that in the early days, when these strata were deposited, enormous quantities of matter were removed by the action of springs from the interior to the outside of the earth. This removal must have left cavities below, into which the crust sank, and in sinking became thus universally corrugated. This he calls the *crenitic* theory of metamorphism. It is obvious that Dr. Hunt's suggestion is in line with that above made, though the phenomena to be explained are much earlier in date and consequently in a more obscure and debatable region. Much less is known of the date and mode of formation of ranges of metamorphic strata than of the Appalachian mountains. What is supposable at one stage need not, however, be absurd at another, and I am glad to be able to quote Dr. Hunt's words, even if only in a slight degree conveying a suggestion similar to my own.

logical problems with great reserve. While he welcomes all aid from this quarter for his difficult tasks, he should not allow a mathematical deduction of the kind above mentioned to prevent his acceptance of a contradictory physical deduction from observed facts. If the latter warrant any inference out of harmony with the former, there is at least a possibility that the latter may be right. And in our discussions regarding the interior of the earth we are in this condition. The data of the problem are as yet too obscure and uncertain for the mathematical engine, and physical deductions from observation claim and deserve at least equal consideration.

If then the facts here detailed justify the interpretation put upon them, they lead to conclusions which, if admitted by a few geologists, have certainly not been generally asserted. If these indications of contraction are acknowledged to the full extent here given, or even to any considerable portion of that extent, they require admissions and lead to conclusions for which all are not prepared, and to which not a few will be strongly opposed. If the eastern seaboard of North America has, by tangential pressure, been shortened so that a line originally 153 miles long now measures only sixty-five miles, the circumference of the earth must be lessened to that extent. Consequently the admission of the statement here made involves an admission that the diameter of the earth was diminished by about one-third of this amount, or that its radius was shortened thirteen miles by contraction during the later part of the Palæozoic era. Geology is not fully prepared for this conclusion, and astronomy is perhaps less ready for it. Yet, unless one or the other can find some better explanation, the unwillingness to admit is not a sufficient reason for rejecting it.

It is not the object of this paper to consider and discuss the various objections that must arise to the conclusion above stated. And such discussion would require more space than can be here occupied. A few words in conclusion must suffice.

Possibly, though in treading on so uncertain a ground and in so dim a light I wish to advance with the greatest caution, aware that every step may be in the wrong direction, yet possibly there are indications to be found elsewhere which may render the inference above drawn a little less startling, even if they do not bring it within the bounds of ready credibility. Spasmodic action with

intervals of repose is a usual mode of operation in nature. Without going back to earlier days, whose events are more obscure, I will consider only the later geological history of our globe. And here are not wanting evidences of similar changes. Admitting that cooling and consequent internal contraction have been, by physical necessity, continuous, there seem to be indications that the subsequent corrugation of the crust has been to some extent spasmodic. Beyond doubt the formation of arches and troughs by compression of the strata has occurred in almost every era. Perhaps when we know the whole earth we may find no time of perfect repose. But since the Palæozoic era ended there has been at least one period during which the process again rose into great prominence, eclipsing perhaps that which it exhibited in Palæozoic days. Anticlinal arches can be found of almost every date in Secondary time. But after the beginning of the Tertiary age, and through a great part of its duration, their development became wonderful. Almost all the great mountain ranges date from this era. Strip from the earth the mountains of Tertiary date and it would lose nearly all its grandest features, and would be reduced to a comparatively monotonous plain. The Rocky mountains and the Andes in the western world, and in the east the Alps, the Apennines, the Pyrenees, the Carpathians and the Himalayas, with other minor chains, all date back to about Mid-tertiary days. And the elevation of so many lofty anticlinal folds, in comparatively a short time, threw into the shade all events of the kind that had occurred since the great Appalachian revolution. It is not yet possible to estimate, still less to measure, the folds of these ranges, but it impossible to doubt that they would yield results scarcely less, and perhaps greater, than those which I have given for Pennsylvania.

What then must be our conclusion? Must we incline to the belief that our earth has much diminished in size since the middle of Palæozoic time? Must we admit that this diminution amounts to many miles? That the radius is thirteen miles shorter than it then was, and the circumference less by six times that amount? Apparently there is no escape.

One word more. Is not the admission reasonable? Is not the denial unreasonable? If the earth is a cooling and contracting globe the result must surely be evident in the long ages that have elapsed since the Appalachian earth-folds arose. If the corru-

gation due to contraction in that interval is inappreciable, what an enormous time must be allotted to the earlier stages of geological history! Even allowing for a greater rate of cooling in those earlier days, the time will surpass all that geologists have demanded, and be more difficult of admission than the contraction here contended for. It is not easy to admit that cooling, contraction and crumpling have been important factors in the formation of the surface of our globe, and at the same time to deny that their action has been perceptible or important since Mid-palæozoic ages, that is during a lapse of time amounting probably to not less than fifteen millions of years.

Further, it is not impossible or improbable that the facts and inferences here detailed may be useful in the solution of some difficult geological problems, especially regarding the older rocks. If mass-motion to so great an extent has taken place in the earth's crust since Palæozoic time began—if the tangential thrust has produced lateral movements in the rocks such as those here described and others which might have been mentioned—if strata have slid bodily over strata for great distances, and whole counties have been shoved for miles out of their previous places, it is obvious that enormous lateral displacement of strata must be recognized as a momentous factor in geology, and that older beds may be found far out of their expected places and even overlying newer ones. Into this subject, however, I cannot now enter, but leave it with the single remark that the greatest caution and reserve must be manifested and every element of doubt eliminated before we can confidently assert that in regions of disturbance the *upper* is the *later* deposit.

I may be allowed to repeat in conclusion that the inferences here deduced do not rest on exact accuracy in the figures employed. Were they considerably in excess of the truth the argument would still hold good. Even the half of the amount of contraction involved would far surpass what geologists have been in the habit of claiming or astronomers of allowing.